Chapter 3: Processing and Conversion

Energy Efficient Harvesting, Dewatering, and Extraction

Convener: John Groppo

Discussion:

Harvesting and dewatering design must consider the energy intensity of the operations and energy return on investment. The classical system is outdated and does not focus enough on upstream impacts on downstream operations. The goals of system design are to minimize energy intensity and overall operating cost.

Operations starting with an algae concentration of 0.5 g/L and through primary concentration/settling to 2 g/L need to be continuous, scalable, and with an optimized retention time. This has not been demonstrated on a continuous basis. Moving to 60 g/L methods include dissolved air filtration, belts, or acoustics, but there is a need for new filtration technology. Centrifuges deal with 100-200 g/L. These system designs should consider multi-product models and account for non-biofuel products. Foreign material removal is important for the filtering process.

Scaling these systems is a major issue requiring advances in engineering and CAPEX. Processes should be engineered in a system-design framework, considering both impacts on upstream and downstream processes. There is a need for data on larger scale processes, utilizing existing facilities; small scale projects do not relate to bigger projects. A databank of process performance at existing facilities would be beneficial to the industry.

Harvesting facilities need products for testing. Small companies need the feedstock producers to provide them with this feedstock for testing, and DOE could facilitate this interaction.

Optimized systems should integrate aquaculture, harvesting, and extraction, as well as investigate co-energy strategies to leverage existing sources of energy to minimize CAPEX.

Guiding Questions:

1. What is the time horizon for this topic or issue; will this impact algal biofuel production in the near, mid, or long term?
    - Efficient harvesting and extraction is a limiting factor for commercialization and so it needs to happen first, within the near term.
2. Has this topic been included in the National Algal Biofuel Technology Roadmap; and if not, should it be?
    - This issue is already discussed in the Algae Roadmap, but deserves more attention.
3. What is the BETO Algae Program role in furthering this topic or addressing this issue?

- The Algae Program should support the small pieces of this issue to facilitate fitting them together.
- The current bottleneck is the limited volume of steady algal biomass, and the Algae Program could facilitate the distribution of this material.
- Access to substrate is also vital.

Poster:

Need for technology development that is continuous and scalable.

- Primary > 2 g/L
- Secondary > 60 g/L
- Tertiary > 100-200 g/L

Objective is to reduce:

- Energy Intensity
- CAPEX/OPEX
- Impacts on upstream and downstream processes
- Foreign material (i.e., sand)

Need to establish databank of process performance at existing facilities.
Need to summarize existing data from various industry and government organizations on process performance.
Need access to substrate for integrated aquaculture/harvesting/extraction system optimization.

Algal Oil Upgrading

Convener: Ryan Davis

Discussion:

Algal oil upgrading is a complex topic, and it is difficult to model as an integrated system.

Discussions in this session focused on pathways to finished fuels and how they compare to one another. The argument for the algal lipid extraction and upgrading technology pathway (ALU) is the value of products vs. cost of upgrading in comparison to hydrothermal liquefaction (HTL).

Challenges and comparisons of HTL and ALU:

- ALU may be an easier process because the extracted lipids are similar to vegetable oil, but with algae the process requires electricity inputs and oil extraction.
- HTL is straightforward but requires more upgrading demands.
- What is known about the range of molecules in the HTL oil phase? How does the bio-crude compare to final product?
    - How much does it cost?
    - How much hydrogen does it consume?
- HTL upgrading on site can increase nitrogen and nutrient recycle.
    - This may be if you ship oil one way and ship nutrients back the other way, but it might not be recovered and you may have to buy it back if it goes to a refinery.

Suggested areas of research for algal oil upgrading (pathway indiscriminant):

- Insertion points in refinery process chain
    - Mostly will be integrated near the front end, but some molecules such as farnesene to farnesane could go into the system at the end.
- Hydrogen demand
- Location (centralized or distributed)
- Scale
    - Minimum scale
    - Economy of scale/co-location
- Refinery buy-in is important
    - Infrastructure (pipelines)
    - Refineries are very risk adverse
    - Refineries won't talk until there are hundreds of barrels of oil
    - Maybe down select
- Pre-processing
    - Pacific Northwest National Laboratory (PNNL) models can simulate 80% bio-crude to diesel
- Can you use solid catalysts in transesterification instead of methanol to change the TEA?
    - Transesterification has not taken part because it is not compatible with infrastructure; it is also less concrete in modeling, and PNNL has in house data

    - HTL does not require high lipids, just carbon, and has increased carbon efficiency; it is a simpler process, and you do not have to dewater as much.
- Supercritical extraction
    - Currently at the bench scale because it is too energy intensive and too costly for a commodity priced fuel.
- Can HTL solids be used as a co-product?

Guiding Questions:

1. What is the time horizon for this topic or issue; will this impact algal biofuel production in the near, mid, or long term?
    - Analysis is needed on upgrading in the near term, and refinery insertion is longer-term (because larger volumes are needed).
2. Has this topic been included in the National Algal Biofuel Technology Roadmap; and if not, should it be?
    - This issue is in the Roadmap, but only a little on upgrading. This could be revisited with more emphasis and maybe now there is enough data to narrow the analysis.
3. What is the BETO Algae Program role in furthering this topic or addressing this issue?
    - BETO should consider technology pathway alternatives, other than HTL and lipid extraction, to keep up to date with innovations.
    - The Algae Program should conduct analysis on location of upgrading and centralization vs. current refinery infrastructure (TEA/LCA for nutrient recovery would be optimized if the system is centralized).
    - The Algae Program should conduct research, development, and analysis on bio-char and nutrient (N/P) recycle.

Poster:

<u>Issues/drivers:</u>
Process

- H2 Demand
- Insertion points in the refinery chain
- Refinery buy-in/communication
- Scale/minimum scale
- Preprocessing demands
- Location: centralized vs. decentralized

DOE Roles:

- Investigate alternative conversion options
- Analysis on scale/location/centralization
- Quantify degree of impact on TEA/LCA for nutrient recovery loss if centralized
- R&D on N/P recycle uptake in cultivation
- Leverage NABC refinery integration studies

Thermochemical Conversion

Convener: Matthew Atwood

Discussion:

The DOE should focus on four main areas in thermochemical conversion and hydrothermal liquefaction (HTL) progress: (1) feedstock and product composition and characterization, (2) pathway optimization, (3) processing issues, and (4) scale-up/commercialization issues.

Thermochemical conversion facilities require consistent deliveries of feedstock, and algae cultivation and HTL development research should be integrated. DOE can help in characterizing feedstocks used in conversion processes. Cost trade-offs related to initial feedstock composition may not be a huge CAPEX issue (temperature variances). Is the cheapest feedstock the best, or is the $/btu more important? Should we look at feedstock/process optimization? These issues may benefit from a Pareto analysis where two parameters are examined to see where optimization occurs.

There needs to be a lot more characterization in terms of understanding algal bio-oil total acid number (TAN), oxygen content, ash content, nitrogen content and phosphorous content, etc., which can greatly impact upgrading processes and product quality because the quality of the oil produced is a huge cost driver. DOE should draft minimum standards for algae, similar to terrestrial feedstocks, to determine the compatibility with downstream processing. It may be beneficial to facilitate partnerships with already running terrestrial thermochemical conversion plants.

DOE is missing alternative thermochemical pathways, and should study more than just HTL technologies. DOE should research wet vs. dry processing (hydropyrolysis vs. HTL) based on the energy return on investment, and may want to investigate integration with solar thermal (in drying and in processing) as well as petroleum and HTL oil blending (co-processing on downstream side). DOE should conduct reactor design and balance-of-plant studies looking at pathway details such as heat integration. The HTL process demands hydrogen, and this input needs to be evaluated. DOE should focus on studying different pathways for bio-oil to final fuels, or “plant-to-pump,” to determine the relative pathway trade-offs.

Processing issues include nutrient recycle and ash separation processes. Nitrogen and phosphorous in the products is a huge issue in upgrading. Wastewater treatment may require further research to determine what is in it and if it can be recycled. It may have to include the solid phase; only a couple groups are currently doing work on the actual recycling of the aqueous phase (AD potential, catalytic gasification). Returning water to cultivation might not be beneficial, and it would need to be determined if you can pull out nitrogen and phosphorous before processing in order to recycle nutrients beforehand. Municipal WWTP combined sites could hold ideal integration and design processes, and integration is the key to minimizing costs. DOE should help facilitate utilization of integrated designs and co-location since there are many variables in this process.

Scaling and commercialization costs are driven by CAPEX and yield (which is affected by seasonality). The DOE should help determine the benefits of co-location and process integration. Models of these pay-offs should be of high-quality. In terms of economies of scale, the minimum scale for piloting may be a continuous pilot scale resource (bridge from bench to commercial) in the 3-5 gal/min (20 L/hr) range, more than 1 kg/day. There was discussion on whether DOE's role should be to fund this intermediate scale at an academic/laboratory scale. DOE could at least help build partnerships for such a piloting activity to take place and could even reach out to current terrestrial thermochemical biorefinery partners to discuss the potential of algal feedstock testing in their systems. This could help in determining bio-oil compositions and refinery and upgrading requirements. How does algal bio-oil go from plant-to-pump best?

Guiding Questions:

1. What is the time horizon for this topic or issue; will this impact algal biofuel production in the near, mid, or long term?
    - The timeframe is 3 to 5 years for pilot/commercial scale.
2. Has this topic been included in the National Algal Biofuel Technology Roadmap; and if not, should it be?
    - Thermochemical processing is discussed in the Algae Roadmap.
3. What is the BETO Algae Program role in furthering this topic or addressing this issue?
    - The DOE should fund areas that have big impacts on cost.

Poster:

1. Scale/commercialization
    a. Bridge gap between lab research and scale-up. (minimum scale)
    b. Process integration/co-location/plant-to-pump

2. Processing Issues:
    a. Separations issues
    b. Quality and cost of feedstock
    c. Nutrient recycle
    d. Fate of heteroatoms
    e. Integration and cost trade-offs

3. Pathways:
    a. Yield
    b. Quality of oil vs. feedstock
    c. Price comparison (vs. HTL)/EROI
    d. Reactor Design plus Balance of Plant
    e. Mechanistic studies/reaction kinetics

TIME: 3-5 years to commercial demonstration

Algal Biomass Fractionation

Convener: Robert McCormick

Discussion:

Algae fractionation facilitates the complete utilization of algae to drive down prices, and to better handle variations. Algae fractionation is an algae biomass processing scheme which uses acid pretreatment to extract the carbohydrates and lipids into the aqueous phase, and the proteins remain in the solid phase. Algae fractionation will fractionate the biomass without using a solvent in order to capture all three components; this provides a higher potential for co-products.

Algae fractionation will generally produce three streams that can be converted to biofuels, for example, proteins to butanol, sugar to ethanol, and lipids to diesel. Glucose and mannose are the primary sugars that are extracted and can be fermented to various products.

The challenge is in the integration of the three separate process streams - lipid, carbohydrates and proteins. Each of these streams will require an independent process unit to produce fuels. Each of the fuels produced from each process stream will most likely be different.

There are different ways to fractionate the feedstock, not just dilute acid. You just need to fracture the cell to fractionate the algae. The preliminary data shows that the dilute acid pretreatment works on all strains tested during three different development stages.

Guiding Questions:

1. What is the time horizon for this topic or issue; will this impact algal biofuel production in the near, mid, or long term?
    - Early stages, this technology will have a midterm impact.
2. Has this topic been included in the National Algal Biofuel Technology Roadmap; and if not, should it be?
    - A fractionation process should be included in the Roadmap.
    - The group recommends including the remaining fractions, not just the lipid phase, into the Algae Roadmap.
3. What is the BETO Algae Program role in furthering this topic or addressing this issue?
    - The DOE can help identify potential industry partners to develop algal fractionation. The DOE could act as a facilitator and leverage similar experience in other biomass fractionations in other tangential fields.
    - The DOE can also help compare an algae fractionation TEA with other conversion routes.
    - The DOE should increase funding levels in order to advance the TRL level to a sufficient point were algal fractionation can be compared to other conversion technologies.

Poster:

A. Offers more flexibility for nutrient recycle, products, and co-products production
B. Meets TEA requirement for full utilization of biomass components

1. Issues – near-term, low TRL; mid-term, scale-up complexity integration; Long-term, demonstration.
2. This is not addressed in the Roadmap – it should be covered.
3. DOE/BETO should:
    a. Identify industry partners
    b. Compare TEA of alternative conversion routes
    c. Cooperate with other DOE agencies
    d. Continue funding to achieve higher TRL for TEA comparisons.